The SCintillator-ECAL Beam Test
at DESY, 2007
— Update 2 —

The CALICE collaboration

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Abstract

A beam test of the SCCEAL prototype module was performed in the period Feb 26 - Mar 28 2007 using 1-6 GeV positron beams at the DESY-II electron synchrotron.

This note describes an update of the analysis presented in previous notes [1] [2]. A correction to take account of cross-talk between strips was developed, and the detector performance after this correction evaluated.

The results presented in this note will be shown at the 2008 ACFA meeting at Sendai.
1 Introduction

This note should be read in conjunction with [1] and [2]. It describes further progress in the analysis of the data collected at the SCECAL testbeam at DESY in 2007.

The crosstalk between adjacent scintillator strips is measured, and a procedure to correct for it is described. The performance of the detector after this correction is evaluated in the three detector configurations.

2 Trigger requirements

The selections applied to the trigger and veto counters (TC1, TC2, VC1, VC2) were slightly changed with respect to those used previously, to reject some additional double beam events. The new selection is summarised below. This selection rejects around 2/3 of the collected events, mainly due to the cut on Veto Counter 2, which rejects events where the positron showers in the scintillator layers during MIP runs.

<table>
<thead>
<tr>
<th>TC1 R</th>
<th>TC2 R</th>
<th>VC1 U</th>
<th>VC1 D</th>
<th>VC2 D</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 1300</td>
<td>≥ 1500</td>
<td>≤ 810</td>
<td>≤ 970</td>
<td>≤ 850</td>
</tr>
<tr>
<td>≤ 3500</td>
<td>≤ 3500</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3 Change in MIP calibration sample

In determining calibration constants for the 3rd configuration in the results presented in previous versions, a number of runs in which a non-standard MPPC bias voltage was applied were erroneously used. This has been fixed in the present version.

4 Light cross-talk

The scintillator strips used in this beam test were not perfectly optically isolated from each other. This is particularly true in the case of the “megastrips” used in the first two modules (“direct readout” and “fibre readout”), where sections (strips) of the tile were isolated by a pair of grooves into which white PET film was inserted. Bench tests had suggested that the light cross talk between these strips was of order 10%. The cross-talk in the third module (using extruded strips) is expected to be smaller, since the strips are mechanically independent, and each is covered by a layer of TiO$_2$. 

2
5 MIP event selection

The measurement of the cross-talk in MIP events requires a change of the event selection, since the previous selection was biased against events with large cross-talk (requirements were made on signals recorded by strips in the same layer as the one being considered, see [1] for details.).

This new selection is summarised in fig. 1. First the reconstructed track was required to intersect the strip in question. Almost all similar (same position) strips in the other detector layers with the same orientation were required to have registered a MPPC signal inconsistent with the pedestal (at least 80 ADC counts above pedestal); no more than two such strips may fail this condition, excepting known dead strips. Additionally, none of the other strips in the two layers before and the two layers after the one containing the strip being considered may have a MPPC signal greater than 80 ADC counts above pedestal.

Fig. 1 also shows the number of selected MIP events per strip, which is generally between 10k and 100k events.

Figure 1: Left: event selection criteria. For the yellow strip to be selected as having had a MIP pass through it, almost all red strips (including those in layers not drawn) must have a signal significantly larger than the pedestal, and all blue strips must be consistent with the pedestal signal. Right: the distribution of the number of selected MIP events per strip, for the three configurations.

6 Measurement of cross-talk

This measurement was made using MIP data (3 GeV positron beam without tungsten plates in the detector), using runs in which the beam was scanned across the whole detector in a square grid of 9x9 points with a pitch of 1cm.
This ensures that the strips are more-or-less evenly illuminated by the beam, and that we measure the strips’ average cross-talk, rather than the cross-talk at a particular region within the strips (e.g. the strips’ centre).

The MPPC signals in the following scenarios were considered: when a MIP had passed through the strip itself; the MIP passed through a neighboring strip in the same layer (separately in the directions along and transverse to the strip length); or the MIP passed through one or none of the other, non-neighboring, strips in the same layer. The mean of the pedestal-subtracted ADC distributions in these five classes of events are considered: $\overline{ADC}_{\text{selected}}$, $\overline{ADC}_{\text{trans}(1,2)}$, $\overline{ADC}_{\text{long}}$, $\overline{ADC}_{\text{other}}$. Examples of these five distributions in a particular strip, in the three types of layer, are shown in fig 2.

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The cross-talk is then defined as

$$\text{xtalk}_{\text{neighbour}} = \frac{(\overline{ADC}_{\text{neighbour}} - \overline{ADC}_{\text{other}})}{\overline{ADC}_{\text{selected}}},$$

separately for the (usually) three neighbours of each strip. (Strips at the edge of the detector and strips next to dead channels clearly have a smaller number of active neighbours.)
In this way the cross-talk across each strip boundary was measured two times, once in each direction. Figure 3 shows the correlation between the two measurements of cross-talk across each boundary, in the direction transverse to the strip length, separately for the three module types. The average value of the cross talk is around 10% (2%) for the megastrip (extruded strip) layers. The cross-talk measured in the two megastrip modules is consistent, as expected (the optical isolation structure is identical). There is significant boundary-by-boundary variation in cross-talk, and the two measurements of each cross-talk probability are consistent. A cross-talk probability was defined separately for each strip boundary, calculated as the mean of these two measurements.

Figure 3 also shows similar plots for the cross-talk in the longitudinal direction (along the strip length). The average cross-talk value is rather smaller than in the transverse direction. The cross-talk in the fibre readout megastrip tends to be smaller than that in the direct readout megastrip. While the two measurements of the cross-talk across each boundary are significantly correlated, it is significantly larger in one direction than in the other. When the cross-talk light enters the neighboring strip at the MPPC end, the signal seen is larger than that seen when it goes the other way, and has to travel the entire length of the scintillator strip before being detected by the MPPC.

7 Cross-talk correction procedure

A cross-talk correction procedure for shower events was developed using the measured cross-talk values.

For each layer, an 18x18 matrix $M$ was constructed. If the true number of MIPs passing through the 18 strips is given by the vector $a$, and the reconstructed number of MIPs (pedestal subtracted ADC divided by calibration constant) is $b$, then $M$ is defined as $b = M \cdot a$. The matrix $M$ has diagonal values of unity, and just-off diagonal elements corresponding to the cross-talk between transverse strips, with two additional groups of off-diagonal elements corresponding to cross-talk in the longitudinal direction.

\[
\begin{pmatrix}
1 & XT_{0,1} & 0 & \cdots & XT_{0,8} & 0 & 0 & \cdots \\
XT_{0,1} & 1 & XT_{1,2} & \cdots & 0 & XT_{1,9} & 0 & \cdots \\
0 & XT_{1,2} & 1 & \cdots & 0 & 0 & XT_{2,10} & \cdots \\
& \vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\
& \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\
& \ddots & \ddots & \ddots & \ddots & \ddots & \ddots & \ddots \\
& \cdots & \cdots & XT_{16,7} & 0 & \cdots & XT_{15,16} & 1 & XT_{16,17} \\
& \cdots & \cdots & 0 & XT_{17,8} & \cdots & 0 & XT_{16,17} & 1 \\
\end{pmatrix}
\]
Figure 3: Correlations between the two crosstalk measurements made of each strip boundary. Top row: transverse direction; lower row: longitudinal direction. Left plots for fibre readout, central for direct readout, and right for extruded strips.
Since this matrix is close to diagonal, it can be inverted without any problems. The inverted matrix can then be applied to the reconstructed number of MIPs (\(b\)) to reconstruct the true number of MIPs in each strip: \(a = M^{-1} \cdot b\), thus correcting for the effects of cross-talk. An example of one of these matrices \(M\) is shown in fig. 4, together with its inverse.

![Cross-talk matrix and its inverse](image)

Figure 4: An example of the cross-talk matrix \(M\) (left) and its inverse (right) used to unfold the cross-talk of one layer (layer 6 of the 2nd configuration).

### 8 Detector performance in electromagnetic showers

This cross-talk correction was applied to shower data (collected with tungsten plates). At first, the most uniform regions of the detector were considered: these consist of four regions centred on \(x, y = \pm 2.25\)cm with respect to the centre of the detector. These four points are at the centre of (4.5cm-long) strips in both layer orientations, and are therefore the furthest from the ends of the strips and the least affected by strip non-uniformities due to finite light attenuation length.

Events in which the positron hit the front face of the ECAL module in one of the 1x1cm\(^2\) square regions centred at these four points, as shown in fig 5, were selected. We refer to these regions as “quarter regions”.

The reconstructed number of MIPs (corrected for cross-talk) at the 6 beam momentum points (1 → 6 GeV/c) are shown in figure 6 for the three detector configurations. Gaussian fits to these distributions are used to measure the energy response and resolution, the results of which are shown in fig. 7, both before and after the cross-talk correction.
Figure 5: Drawing of the front face of the detector, showing the strips in each orientation, and the position of the MPPCs. The “quarter regions” are shown as the four dark squares.

The energy responses of the three configurations are consistent after the application of the cross-talk correction. Without the cross-talk correction, the response of the third configuration is significantly smaller than that of the other two. This was due to the large cross-talk in the first two configurations giving rise to a larger reconstructed energy.

The energy resolution in the central region shows large differences between the configurations, the performance of the third configuration is significantly worse than that of the others, and the second configuration performs slightly worse than the first. These differences as significantly smaller when events in the quarter regions are considered, where the first two configurations have essentially identical performance, and the third configuration has only slightly worse resolution. This confirms that the main reason for the worse energy resolution of the third configuration is the non-uniformity of the response along its length, due to its short light attenuation length (see [2] for more details).

Results of (stochastic $\oplus$ constant term) fits to the measured resolution are shown below.

<table>
<thead>
<tr>
<th>detector region</th>
<th>quarter, no xtalk</th>
<th>quarter, xtalk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_E/E = a/\sqrt{E} \oplus b$</td>
<td>$a$</td>
<td>$b$</td>
</tr>
<tr>
<td>configuration 1</td>
<td>14.09 ± 0.07</td>
<td>2.63 ± 0.09</td>
</tr>
<tr>
<td>configuration 2</td>
<td>13.79 ± 0.08</td>
<td>3.04 ± 0.08</td>
</tr>
<tr>
<td>configuration 3</td>
<td>14.66 ± 0.08</td>
<td>2.68 ± 0.11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>detector region</th>
<th>centre, no xtalk</th>
<th>centre, xtalk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_E/E = a/\sqrt{E} \oplus b$</td>
<td>$a$</td>
<td>$b$</td>
</tr>
<tr>
<td>configuration 1</td>
<td>13.38 ± 0.05</td>
<td>2.39 ± 0.07</td>
</tr>
<tr>
<td>configuration 2</td>
<td>13.66 ± 0.06</td>
<td>3.41 ± 0.05</td>
</tr>
<tr>
<td>configuration 3</td>
<td>14.74 ± 0.08</td>
<td>6.52 ± 0.05</td>
</tr>
</tbody>
</table>
Figure 6: Reconstructed energy distributions in the quarter regions, after the cross-talk correction. Different colours show different beam momenta, and three plots are for the three detector configurations.

9 Longitudinal shower profiles

Longitudinal energy profiles in the central region, without any cross-talk correction, are shown in fig. 8. The profiles are not smooth, showing significant discontinuities. Figure 9 shows the same profiles in the quarter regions after the application of the cross-talk correction. The profiles are much smoother, although there are still a few places where small discontinuities are seen, particularly at the boundary between the two detector half-modules.

This improvement in the profiles is due to both the cross-talk correction - there is quite significant variation in the cross-talk between different layers, even of the same type, and also due to the generally better behaviour of the detector in the quarter regions. The remaining non-smooth structures may be due to dead strips in the calorimeter, or to some other, as yet unknown, factors.
10 Conclusions

The cross-talk between strips was measured, and found to be of order 10%, with significant variation between strips and layers of different types. A procedure to correct for this effect was developed, and applied to shower data. This solved the previous problem of different energy responses of the three detector configurations.

The performances of the most (“quarter regions”) and least (detector centre) uniform detector regions were compared. The performance of the three configurations is very similar in the uniform region, while the non-uniformity of the extruded strips causes the third configuration to have significantly worse performance in the least uniform region.

The longitudinal energy profile distributions are reasonably smooth in the uniform regions after the application of the cross-talk correction.

References

[1] CALICE analysis note 005.
Figure 7: Energy response (left) and resolution (right) for the three detector configurations. Top: quarter regions without cross-talk correction; centre: quarter regions with cross-talk correction; bottom: central injection with cross-talk correction.
Figure 8: Longitudinal shower profile in central events, without cross-talk correction.
Figure 9: Longitudinal shower profile in the quarter regions, after the cross-talk correction.